AD-A158 002 CONDENSATION POTENTIAL IN HIGH THERMAL PERFORMANCE WALLS HOT HUMID SUMMER CLIMATE(U) FOREST PRODUCTS LAB MADISON WI G E SHERWOOD JUL 85 FSRP-FPL-455 1/1

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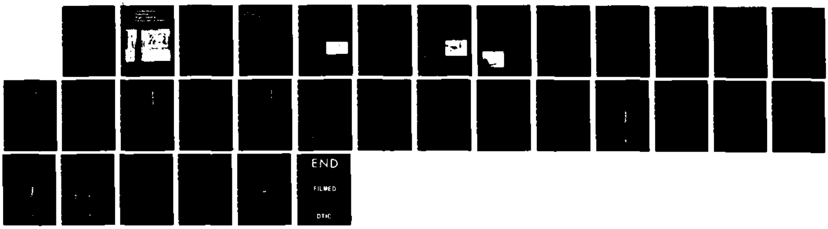

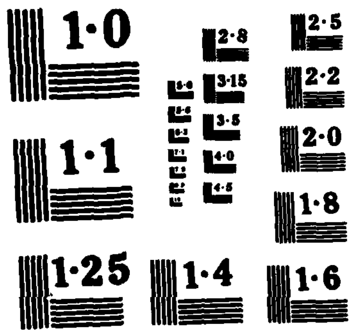

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Condensation Potential in High Thermal Performance Walls

Hot, Humid Summer Climate

Gerald E. Sherwood

Abstract

As a result of steadily rising energy costs, construction practice for light-frame wood structures has changed over the past few years. The use of 6-inch-thick walls and application of high "R" value, low-permeance sheathings to 4-inch walls has caused concern for the changing moisture patterns that may occur in the wall. Excessive moisture in wall cavities can have detrimental effects including decay of wood components if the moisture remains for extended periods coincident with warm temperatures. To observe actual moisture patterns and the potential for condensation due to long periods of air conditioning in a hot, humid climate, a test structure was constructed near Gulfport, Mississippi, for exposure of eight types of insulated wall panels at controlled indoor conditions and typical outdoor weather conditions. Panels were instrumented with moisture sensors and tested without (Phase 1) and with (Phase 2) penetrations (electrical outlets) in the indoor surface.

There was no sustained condensation in any of the walls during either winter season. One type of high thermal performance wall had sustained condensation during both summers, but the wall dried out as the weather became cooler, and moisture content of framing never exceeded 17 percent. Low-permeance sheathing appeared to provide resistance to the buildup of moisture during summer in walls with high overall "R" values. Penetrating the walls with electrical outlets resulted in slightly higher moisture levels in all of the walls throughout the year. This paper should be useful to building designers, builders, and building code officials in establishing vapor retarder requirements for walls.

Keywords: Condensation, moisture control, vapor retarder, air leakage, wood-frame walls, foam sheathing.

Acknowledgments

The author acknowledges the valuable contributions of Doug Wheeler, formerly of FPL, in instrumenting the test structure and providing electronics expertise throughout the 2-year study. Thanks also go to Terry Niedziela, also formerly of FPL, for his creative solutions to problems during the construction, instrumentation, and installation of test panels.

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Condensation Potential in High Thermal Performance Walls

Hot, Humid Summer Climate[1]

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Introduction

High-efficiency thermal insulation systems for wood-frame residential construction have become essentially standard for many parts of the country in recent years. These systems include rigid foam wall sheathing, foil-backed foam wall sheathing, or nominal 6-inch wall studs with 6-inch insulation batts, all of which provide walls with higher "R" values and lower perm values. The higher "R" values will result in colder surfaces with greater condensation potential and lower perm values will restrict moisture movement. Theoretically, all of these systems should result in within-wall moisture patterns different from those of conventional walls with nominal 4-inch studs and wood or woodbase sheathing materials.

Studies were conducted to evaluate the potential detrimental effects of moisture accumulation in wall cavities in both a cold climate and in a hot, humid climate with a long air-conditioning season. Results from the cold climate were reported in a previous paper (Sherwood 1983). Results from a hot, humid climate—i.e., Gulfport, Mississippi—are reported in this paper. In that location, average temperatures during summer months are 80 to 83 °F with frequent highs approaching 100 °F. Average relative humidities during summer months are 85 percent at 4 a.m. (coolest time of day) and 64 percent at 1 p.m. (warmest time of day).

Excessive moisture in wall cavities can have several detrimental effects. It may decrease the effectiveness of the cavity insulation (Joy 1957). If the cavity remains wet for extended periods coincident with warm temperatures in the wall, wood structural components may decay. Under winter conditions, condensation tends to be on sheathings or siding. Outdoor temperature and indoor humidity are the critical variables since indoor moisture is moving toward the drier outdoors and will condense if sheathing or siding are below dewpoint temperature. The result may be buckling or warping of siding or paint peeling (Anderson and Sherwood 1974). Under summer conditions, condensation tends to occur on the back of gypsum board or on the vapor retarder if one is installed. Indoor temperature and outdoor humidity are the critical variables since outdoor moisture is moving toward the drier air-conditioned space and will condense if the gypsum board or vapor retarder are below dewpoint temperature. The result may be buckling of interior finish materials or mildew and mold on the surface.

The potential for these detrimental effects can be assessed based on measurements of moisture levels at various locations in walls exposed on one side to a complete annual cycle of outdoor weather conditions while having the opposite side exposed to indoor conditions with controlled temperature and humidity. A better understanding of the moisture patterns in these highly thermal-efficient walls is needed in order to establish moisture control practices.

This study is part of an ongoing program of thermal/moisture research at the Forest Products Laboratory (FPL) to determine the potential for condensation in walls. Because all variables could not be considered in a single study, additional studies are planned in both controlled laboratory tests and field observations of complete houses.

[1]This research was conducted in cooperation with the American Hardboard Association, Dow Chemical, U.S.A., Jim Walter Research Corporation, and the U.S. Department of Housing and Urban Development.

Background

The results of previous research at FPL on moisture condensation in walls have been summarized (Anderson and Sherwood 1974). General recommended practice applies mostly to cold climates, but there is concern for how warm the winter must be to eliminate the need for a vapor retarder on the inside face of the wall. There is also concern that an outside vapor retarder may be needed during hot, humid summers to reduce moisture movement to the interior face of the wall. Closed-cell foam sheathings or foil-backed foam sheathings act as outside vapor retarders, and could reduce moisture movement toward the inside in the summer.

The fact that moisture reduces the thermal resistance of insulating materials was established by Joy (1957) in the 1950's. A more recent study by Burch and Treado (1978) showed that for certain conditions, condensation occurred as a thin film on cold surfaces and had minimal effect on rate of heat transfer because it did not wet the insulation. However, wet insulation has been found in walls after prolonged periods of condensation. In some cases the condensation runs to the bottom of the wall cavity, saturating the sole plate as well as the lower few inches of insulation.

Moisture also reduces the thermal resistance of wood and wood products. A method for estimating that reduction is presented in the Wood Handbook (USDA 1974). More serious effects of moisture on wood are dimensional changes and the potential for decay, though this author is not aware of documented reports of extensive decay in wood-frame walls due to condensation. Such decay is a greater threat in warm climates than in cold climates because decay fungi require temperatures above 40 °F for growth (USDA 1974). The most visible problems are mildew and paint peeling or blistering.

Previous air-conditioning studies have been conducted in the relatively mild climate of Athens, GA (Duff 1971), but no documented studies from hot, humid climates are available. The actual moisture patterns through the cross section of a variety of walls exposed to outdoor conditions are needed to evaluate the effect of construction types. This can best be accomplished by exposure structures in more than one climate to include the effect of climate on moisture patterns.

Materials and Methods

Exposure Structures

Two structures were built for the purpose of exposing test walls to outdoor weather conditions on one side while exposing the opposite side to typical indoor conditions. One structure was erected near Madison, WI, the other near Gulfport, MS. The two locations were planned to provide data on moisture patterns in a cold winter climate and in a hot, humid climate. This paper is limited to tests at Gulfport. Results from the Madison building were discussed in a previous report (Sherwood 1983).

The buildings are long and narrow, 8 feet wide by 48 feet long, with the long axis east-west for maximum exposure of north and south walls (fig. 1). The center 8-foot-long section is an instrument room. The remaining length of the building is partitioned every 4 feet resulting in ten 4- by 8-foot rooms (fig. 2) connected by doors in partitions. The only exterior door is in the instrument room. Support for the roof and ceiling is provided by partitions (fig. 3), so exterior wall panels can be removed and replaced while the building remains intact. Four- by eight-foot wall panels were completely instrumented during fabrication and then installed by lag bolting them to partitions. Identical panels were installed on north and south walls for extremes of exposure. Both the ceiling and floor are insulated with R-38[2] glass-fiber batts to limit heat transfer so the walls would be the major element of heat loss from each room.

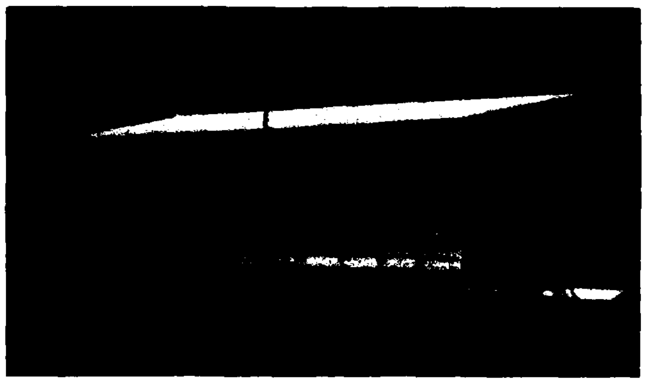

Figure 1.—Experimental structure near Gulfport, MS. (M150 968-22)

[2] "R" is a measure of insulating value or resistance to heat flow. It is the reciprocal of conductance, which is the amount of heat in Btu's that will flow in 1 hour through 1 square foot of homogeneous material per 1 °F temperature difference between surface of materials.

Sheathing, insulation & vapor barriers for walls	Total "R" (Calculated)	Calculated outdoor temp. for freezing at sheathing-insulation interface, °F
Fiberboard, R-13 batt, 6-mil polyethylene	16.13	27
Fiberboard, R-11 blanket, asphalted paper	14.13	26
Plywood, R-11 blanket, asphalted paper	13.53	28
Fiberboard (6" stud), R-19 batt (compressed), 6-mil polyethylene	21.13	28
Extruded polystyrene foam, R-13 batt, 6-mil polyethylene	20.27	15
Extruded polystyrene foam, R-11 blanket, asphalted paper	18.31	13
Foil-backed, GF-reinforced polyisocyanurate foam w/vent strip, R-13 batt, 6-mil polyethylene	23.21	9
Foil-backed, GF-reinforced polyisocyanurate foam, R-13 batt, 6-mil polyethylene	23.21	9

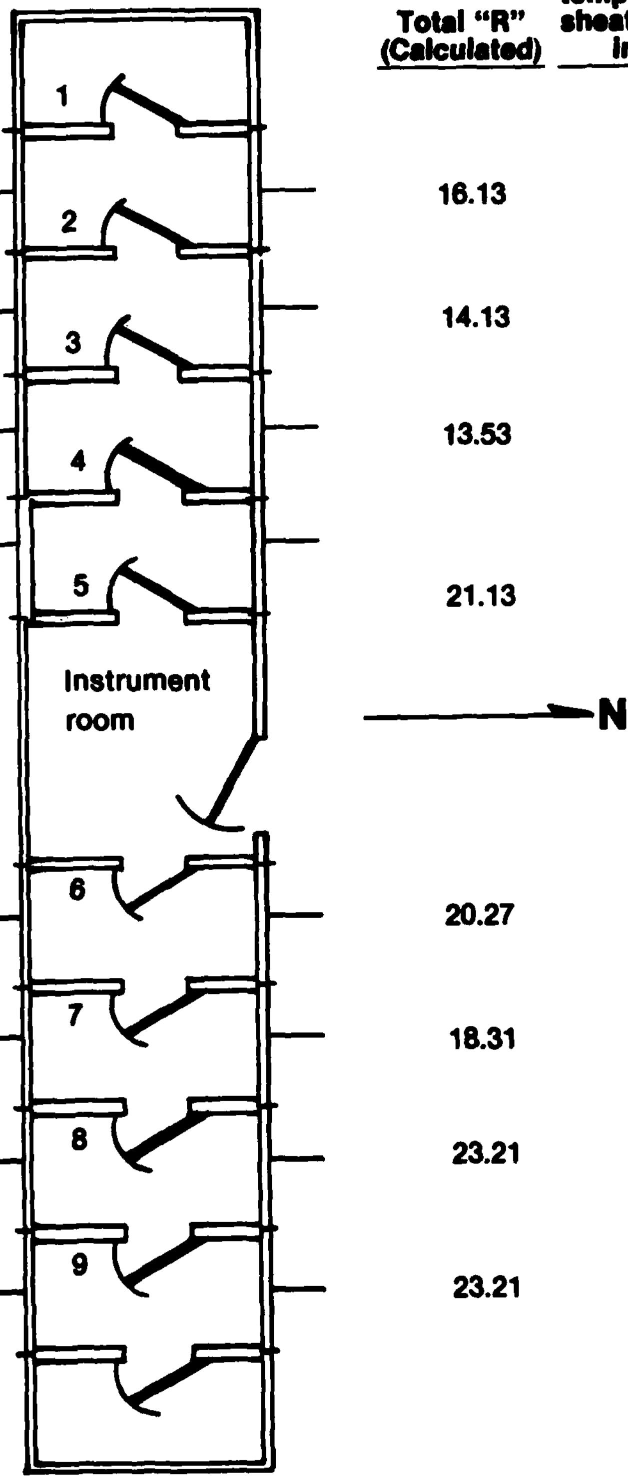

Figure 2.—Plan of experimental structure showing variables of construction for each wall panel. (ML83 5060)

Rooms are individually heated by a resistance-type electric heater, and individually cooled by a window-type air conditioner mounted in the floor. Humidification is available by a vaporizing-type humidifier in each room during the heating season, but was not needed to maintain a relative humidity (RH) above 40 percent. Humidity is not controlled during the air-conditioning season. Heaters are controlled by wall thermostats to maintain a temperature between 67 and 70 °F. Air conditioners are set to cycle on at 79 °F and off at 76 °F. Heating season RH is maintained at a minimum of 40 ± 5 percent. Ceiling fans operate when either the heater or the air conditioner was running.

End rooms are considered buffers rather than test rooms as they have an 8- by 8-foot end wall exposed to the exterior and would not have heat loss, heat gain, or water-vapor loss comparable to other rooms with only a north and south wall exposed. This leaves eight identical rooms in each building for test and comparison purposes. Test panels of the same construction are inserted on north and south exposures of a room, so there is only one type of wall construction for each room.

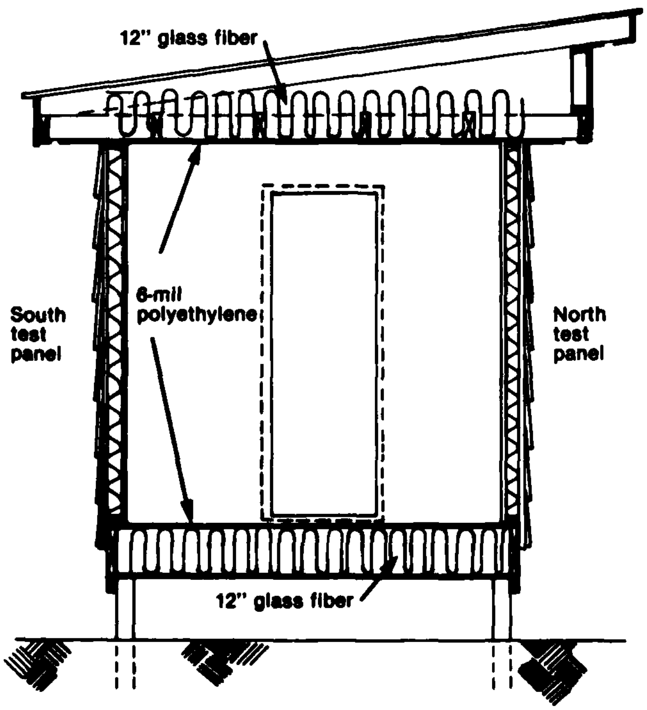

Figure 3.—Cross section of experimental structure showing construction details. (ML83 5061)

Test Panels

For this study, all test panels have 1/2-inch gypsum board on the inside and 7/16- by 12-inch primed hardboard lap siding on the outside. Hardboard was painted after panels were fabricated. Full-thickness glass-fiber insulation was placed in each wall cavity. One type of panel was framed with 2 by 6 studs at 24-inch spacing; all other panels were framed with 2 by 4 studs at 16-inch spacing. The primary variables are the sheathing material and the vapor retarder (fig. 2). In addition, one panel with foil-backed polyisocyanurate foam was vented at the top. Polystyrene sheathing was in 2- by 4-foot sections; all other sheathings were in 4- by 8-foot sections. Sheathing materials included: 1/2-inch fiberboard, 1/2-inch plywood, 1-inch extruded polystyrene foam, and 1-inch foil-backed glass-fiber reinforced polyisocyanurate foam. Only two types of vapor retarders were used: 6-mil polyethylene film continuous over the face of the framing (fig. 4), or asphalted kraft paper backing on blanket insulation stapled between studs (fig. 5). Although the asphalted kraft paper could be installed by the recommended method of lapping all joints over studs, in field practice it is often stapled between studs with no laps (fig. 5). That method was followed to simulate typical field conditions.

Figure 4.—Six-mil polyethylene film being applied as a continuous vapor retarder on an experimental panel. Lead wires to moisture sensors and thermocouples are brought through a small slit that is thoroughly caulked to preserve the integrity of the vapor retarder. (M147 188-11)

Each test panel was instrumented with moisture sensors at 11 locations in the wall (fig. 6). A thermocouple was also placed at each moisture sensor location. At heights of 1 and 7 feet above the floor, moisture measurements were made at the siding-sheathing interface, at the sheathing-insulation interface, at the center of the cavity insulation, and in the adjacent stud. Sensors were also located in the center of the top plate, the center of the sole plate, and between siding and sheathing at the midheight of the wall. Since the purpose of the study was to monitor the moisture content (MC) of wood components, there was no moisture sensor placed at the vapor retarder interface. Brief periods of condensation could have occurred there and been undetected unless the condensation affected MC of insulation or ran down to the sole plate. Lead wires from all these data points were brought into the room through the vapor retarder and gypsum board at two points (1 and 7 feet above the floor). The punctures in the vapor retarders were caulked around each wire individually (fig. 4).

All test panels were without open punctures in the gypsum board or vapor retarder for the first year—Phase 1—of the study. In the second year of testing—Phase 2—a standard duplex electrical outlet was installed in each wall panel to observe the effect of air leakage into the wall cavity. In conventional construction, joints around windows or at baseboards and other discontinuities in the vapor retarder may result in additional leakage. For this study the electrical outlet was selected as uniform penetration to provide air leakage for comparison purposes.

After installation of test panels, all joints with floor, ceiling, and partitions were caulked. On the outside, vertical joints between panels were caulked, and the joint between floor framing and the bottom edge of the wall panel was caulked. Six-mil polyethylene taped to each face of the partitions extends out between adjoining panels to prevent transfer of moisture between panels (fig. 1).

Figure 5.—Asphalted kraft paper vapor retarder stapled to sides of studs. (M147 191-11)

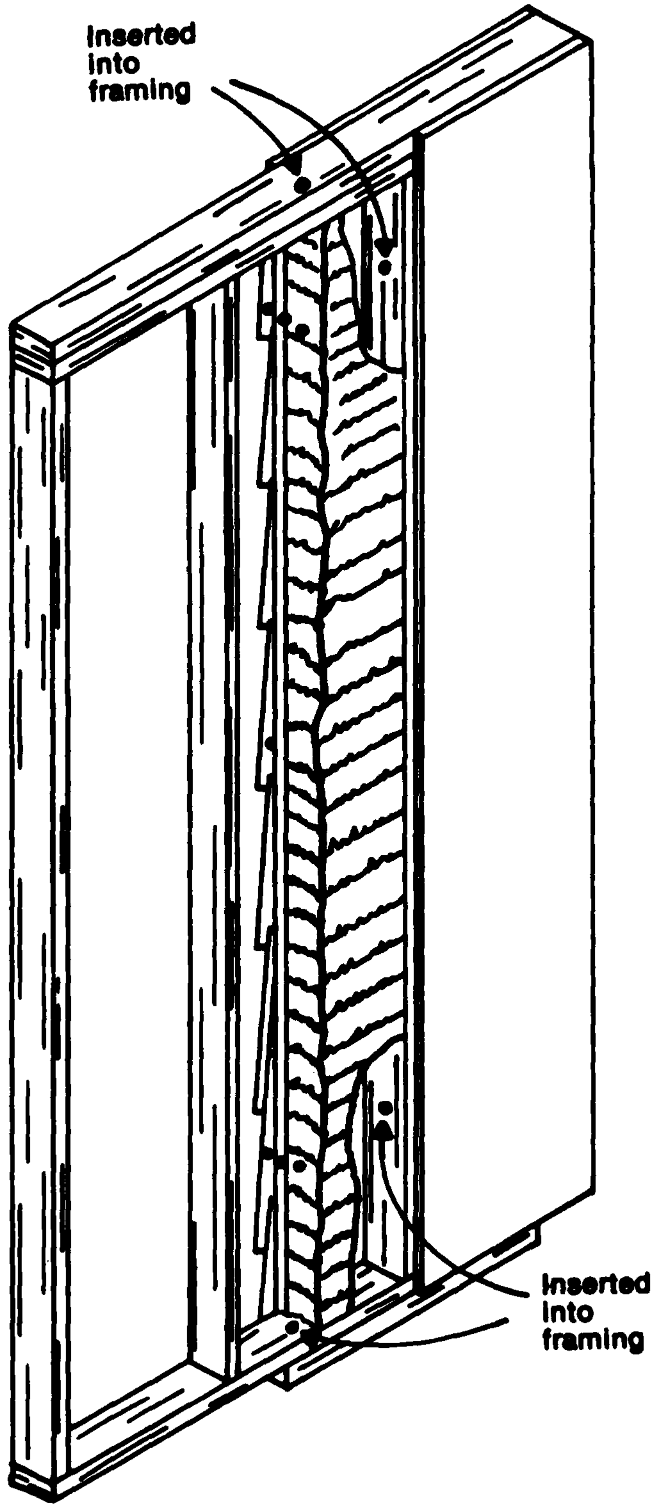

Figure 6.—Moisture sensor locations (•) in each test panel: Four sensors are in the framing; two are in the center of insulation; two are at the insulation-sheathing interface; and three are at the sheathing-siding interface. (ML83 5062)

Data Acquisition

Moisture Content

Moisture conditions were measured at 176 locations in the walls (*fig. 6*) *using small wood sensors. The MC of the wood* sensor was converted to MC of the members in which they were imbedded, or MC at the interface between two materials based on the RH of the air in the immediate vicinity. The RH in the rooms and outdoors was also recorded.

The sensors were calibrated wood elements in which electrical resistance changed with MC of the wood. Construction and details of operation of this sensor are given by Duff (1966). The sensors were calibrated in humidity rooms to an accuracy of ±2 percent MC over an RH range of 35 to 90 percent, which corresponds to an MC in the wood sensor of 7 to 20 percent. Determination of MC beyond these limits was less accurate due to difficulties in measuring extreme ranges of resistance and beads of condensed water often present on surfaces at sensor readings of 20 percent or higher.

To effectively measure the very high resistance inherent in the sensor and to accurately transmit data to the logger, amplifiers were located as close to each sensor as practical; their output was connected to the data logger and calibrated (fig. 7).

The resistance readings were first converted to MC for the sensor species and corrected for temperature effects. Further conversions were then made to provide the MC of the species of the wood sensor in structural members or to provide the RH of ambient air conditions.

Temperature

Temperature measurements were made at each wood sensor with a type T (copper-constantan) thermocouple and used for the temperature corrections.

Data Recording

All of the moisture and temperature data were digitized and recorded on cassette tape using a multichannel, programmable data logger. Readings were made three times per day at 1 a.m., 9 a.m., and 5 p.m.

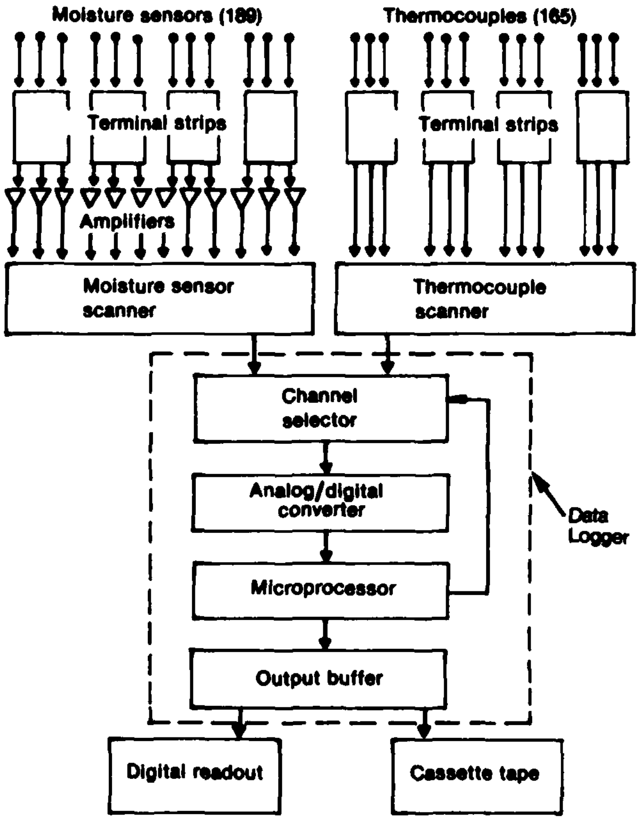

Figure 7.—Flow chart of instrumentation and data recording system. (ML83 5063)

Results

Examination of the building after completion of the test revealed that panel 7S had a large gap between the sole plate and the sheathing, as the result of damage during construction. Since this allowed outdoor air movement into the wall cavity, data from this panel are not reported in the results.

Phase 1—No Penetrations

During the first year of operation, there was little change in moisture levels in the fall and spring seasons, thus moisture levels will be discussed only for winter (December 1979-February 1980) and for summer (June-August 1980). Heating and cooling degree-days for the time periods are shown in table 1. During winter, the north exposure is the most severe, so plots of MC in *north* panels are shown for December 1979 and January and February 1980 (figs. 8-15). For summer, the south exposure is generally more critical, so plots of MC in *south* panels are shown for June, July, and August 1980 (figs. 8-15). High and low outdoor temperatures for these time periods are recorded in figure 16.

Although south facing walls have been considered more critical for summer condensation, the results of this study showed that only the panels with wood-base sheathing had *greater moisture rise in south walls than in north walls*. This trend did not exist in walls with foam sheathing. A possible explanation is that when the sun heats the sheathing on the south wall, water evaporates from both surfaces of the sheathing and, thus, moisture is drawn into the center of the wall. When the sun goes down, water is reabsorbed from outside air so there is a net flow of water into the wall cavity roughly equal to the amount that evaporated into the cavity earlier. This type of moisture flow happens only if the sheathing is hygroscopic. Since wood is hygroscopic and foam is not, the difference in north and south walls is seen only in the walls with wood-base sheathing.

The MC at most data points in the building remained low (<12 pct) throughout the winter. Only three moisture probes rose above the 12 percent level (table 2), and these were not sustained for long time periods. All of these moisture probes were located in framing members: one each in panels 4N, 8N, and 9N. *Since there was no rise in moisture level of the wall cavity, these peaks were apparently not the result of condensation but were probably the result of some outside moisture influence.* The results of the study indicated that winter condensation is not a problem with any of the types of walls tested in the climate of Gulfport, MS. However, all of the walls tested had some type of vapor retarder.

Table 1.—Summary of heating and cooling degree-days for the study time periods

Month	Heating degree-days (65 °F base)	Cooling degree-days (80 °F base)
	PHASE 1	
December 1979	416	
January 1980	323	
February 1980	444	
June 1980		62
July 1980		128
August 1980		83
	PHASE 2	
December 1980	441	
January 1981	578	
February 1981	322	
June 1981		60
July 1981		98

During the summer, all of the 4-inch walls with no foam sheathing (2S, 3S, and 4S) had MC's in the low range at all data points (table 2) with one exception. Panel 2S had one probe with MC's slightly into the moderate (12-16 pct) range, but this was located between sheathing and siding, which *indicates some interaction with outside moisture* such as rain or humid air, rather than wall-cavity moisture. All of the panels with foam sheathing (6S, 8S, and 9S) had MC's reaching moderate or high (16-20 pct) levels in the center of the insulation, but only one of these panels had elevated MC's that were sustained beyond two readings (table 1) and condensation (>20 pct MC) was not indicated at any time. All framing remained at low MC for those panels with foam sheathing. The one panel that had condensation as well as a rise in MC of framing members was 5S.

Panel 5S had indication of condensation in the insulation near the top of the wall during most of the summer. In addition, the sheathing and framing near the top showed substantial increases in MC, though only into the moderate range. In September, the wall was opened for a visual check and the insulation was found to be wet enough that water could be squeezed from it. Direct measurements with a moisture meter showed the studs and top plate had MC's of 15 to 16 percent which generally verified moisture-probe readings. The wet moisture probe in panel 5S was replaced to avoid future malfunction due to fungal growth.

For comparison, a panel with foam sheathing and a 4-inch wall panel with fiberboard sheathing were opened and inspected. In both cases the framing MC was in the 11 to 12 percent range, which also verified the moisture-probe readings. There was also no visual indication of condensation, such as waterstains, in either of these two walls.

None of the panels had moisture levels in the framing that would support decay; water in the insulation in panel 5S was visible evidence of conditions that could lead to decay if continued over a long time period. Also, as with other studies (Joy 1957), the effectiveness of the insulation was greatly reduced by the water.

The overall results from the walls without penetrations in the vapor retarder are summarized as follows:

1. No condensation was detected in any of the walls tested during winter. However, all of the walls had some type of warm-side vapor retarder.
2. The framing in all but one panel was at 11 to 12 percent MC throughout the summer.
3. The wall panel with 6-inch studs had condensation in the insulation near the top through all of the summer months (June, July, and August) and the MC of framing was 15 to 16 percent by the end of summer.
4. Walls with wood-base sheathing had greater increase in MC on the south than on the north; this trend was not observed in walls with foam sheathing.

Table 2.—Humidity as indicated by moisture content[1] of wood probes in insulation and framing during Phase 1 (no penetrations). Elevated MC's are considered only where at least three consecutive readings are in that range

Panel No.	Insulation-sheathing interface			Sheathing-siding interface			Panel No.	Insulation			Framing		
	December	January	February	December	January	February		June	July	August	June	July	August
2N	Low	Low	Low	Low	Low	Low	2S	Low	Low	Low	Low	Low	Low
3N	Low	Low	Low	Low	Low	Low	3S	Low	Low	Low	Low	Low	Low
4N	Low	Low	Low	Low	Low	Low	4S	Low	Low	Low	Low	Low	Low
5N	Low	Low	Low	Low	Low	Low	5S	Condensation[3]	Condensation[3]	Condensation[3]	Low	Low	Moderate
6N	Low	Low	Low	Low	Low	Low	6S	Low	Low	Low	Low	Low	Low
7N	Low	Low	Low	Low	Low	Low	[2]7S	—	—	—	—	—	—
8N	Low	Low	Low	Low	Low	Low	8S	Low	Low	Low	Low	Low	Low
9N	Low	Low	Low	Low	Low	Low	9S	Low	Moderate	Moderate	Low	Low	Low

[1]Low = <12 percent MC; moderate = 12 to 16 percent; high = 16 to 20 percent; condensation = >20 percent.
[2]Data from panel 7S are not shown because construction damage allowed intrusion of outdoor air into the panel, thereby invalidating the data.
[3]*Range of humidity was not replicated on opposite facing walls for the same time period. The reasons for differences were not resolved, and indicate the need for further study.*

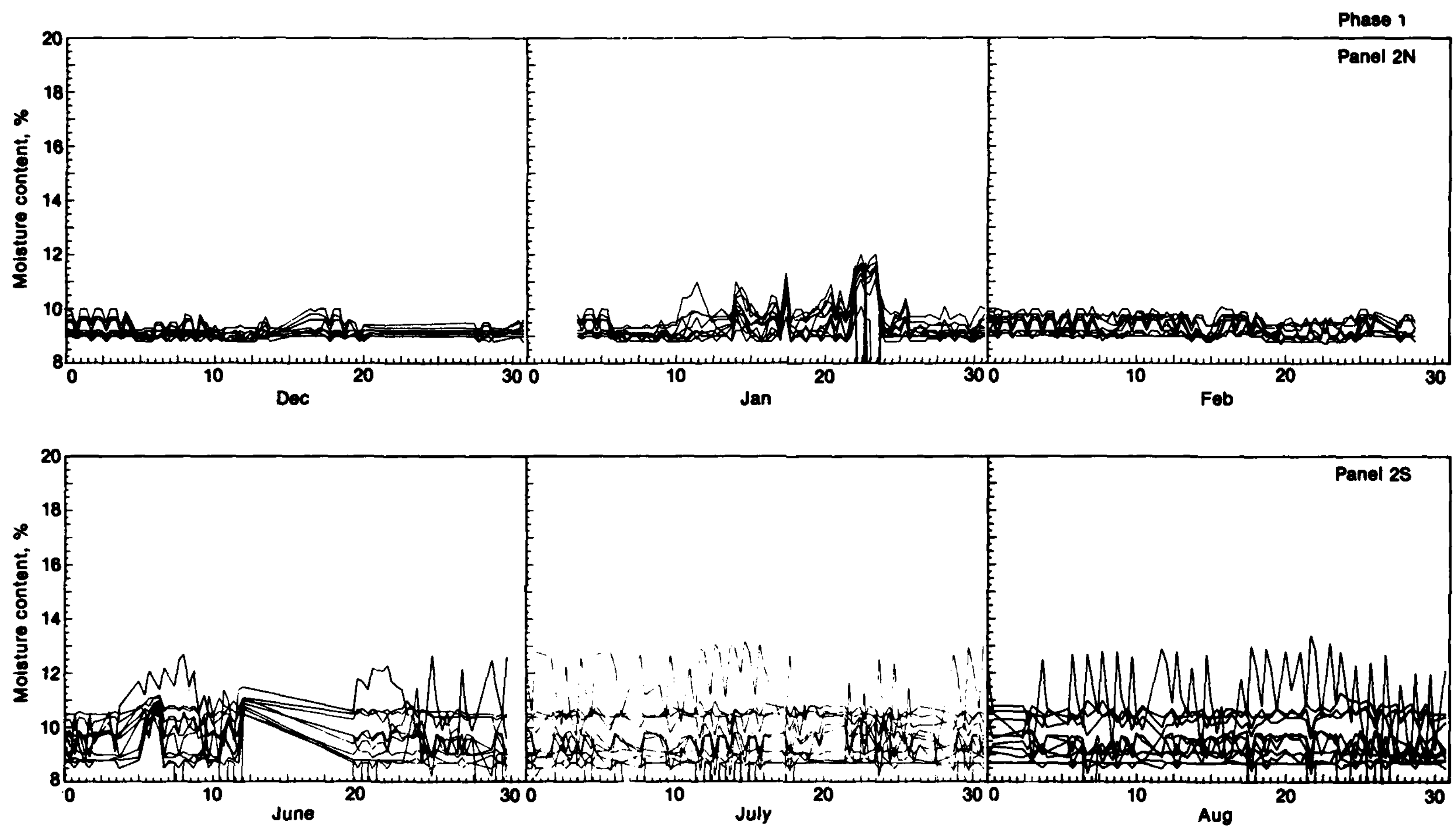

Figure 8.—Moisture content of wood probes in panel 2N (polyethylene, R-13 glass fiber, fiberboard), December 1979 through February 1980; and in panel 2S, June through August 1980. (ML85 5042)

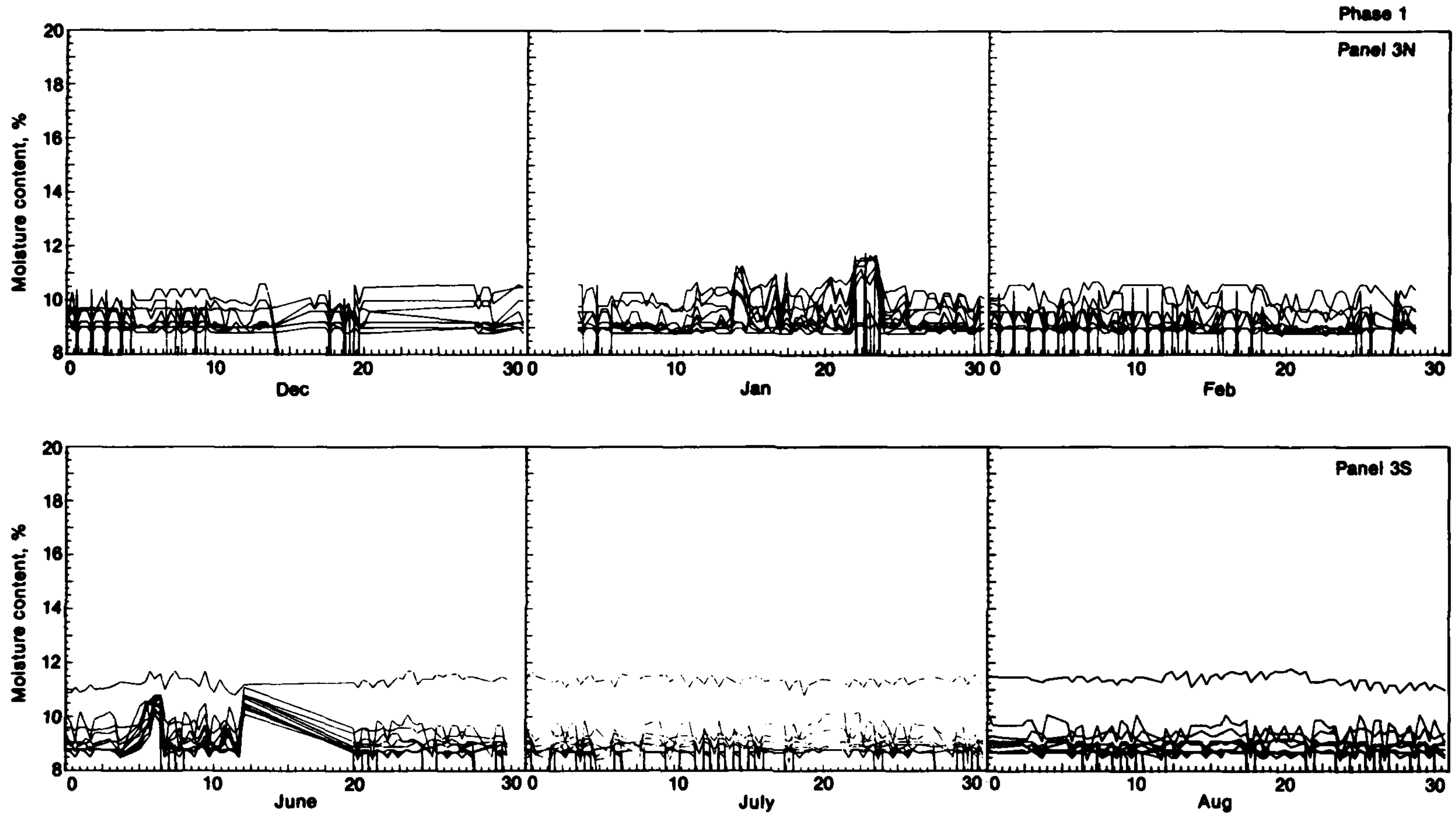

Figure 9.—Moisture content of wood probes in panel 3N (asphalted paper, R-11 glass fiber, fiberboard), December 1979 through February 1980; and in panel 3S, June through August 1980. (ML85 5043)

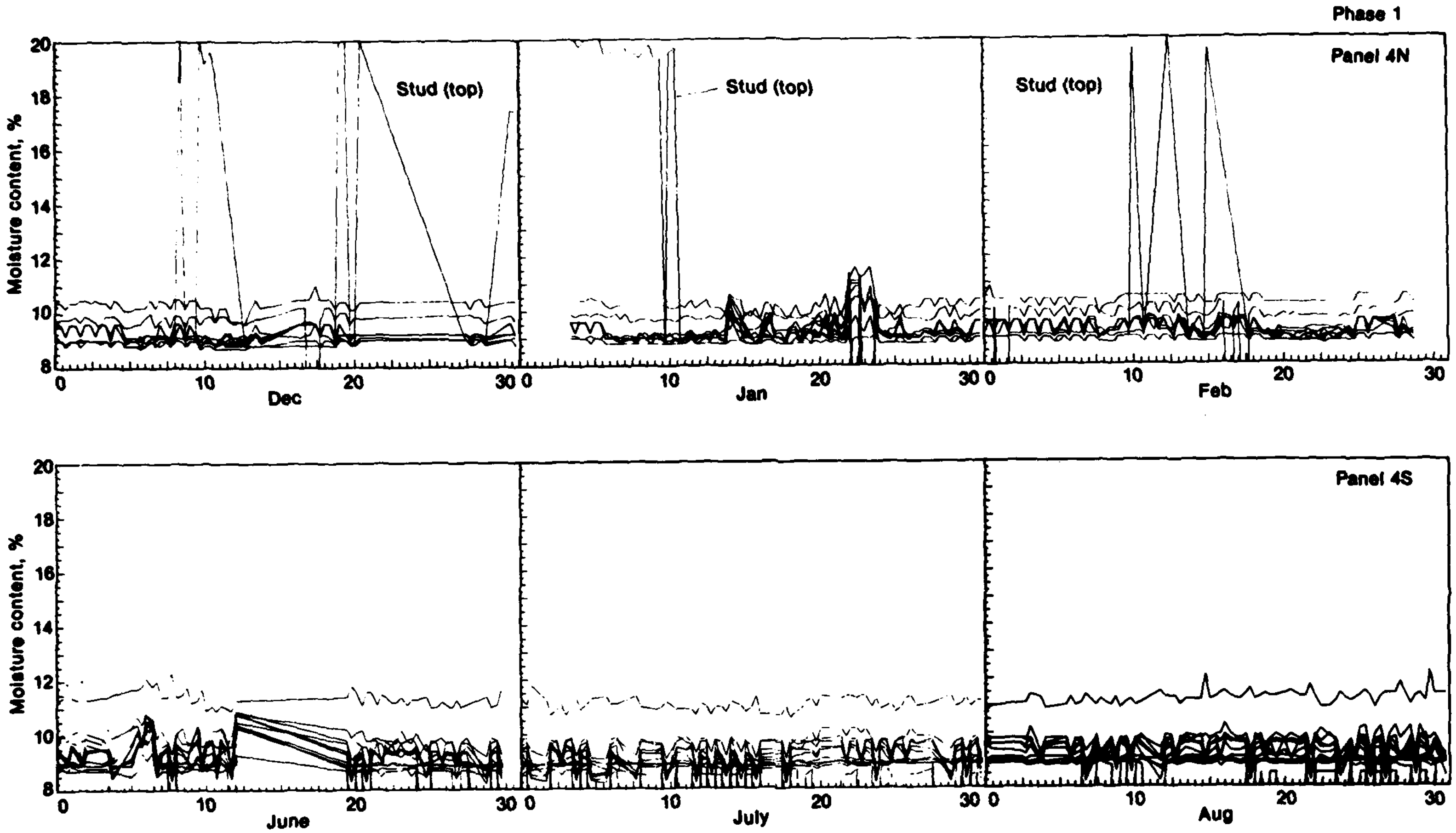

Figure 10.—Moisture content of wood probes in panel 4N (asphalted paper, R-11 glass fiber, plywood), December 1979 through February 1980; and in panel 4S, June through August 1980. (ML85 5044)

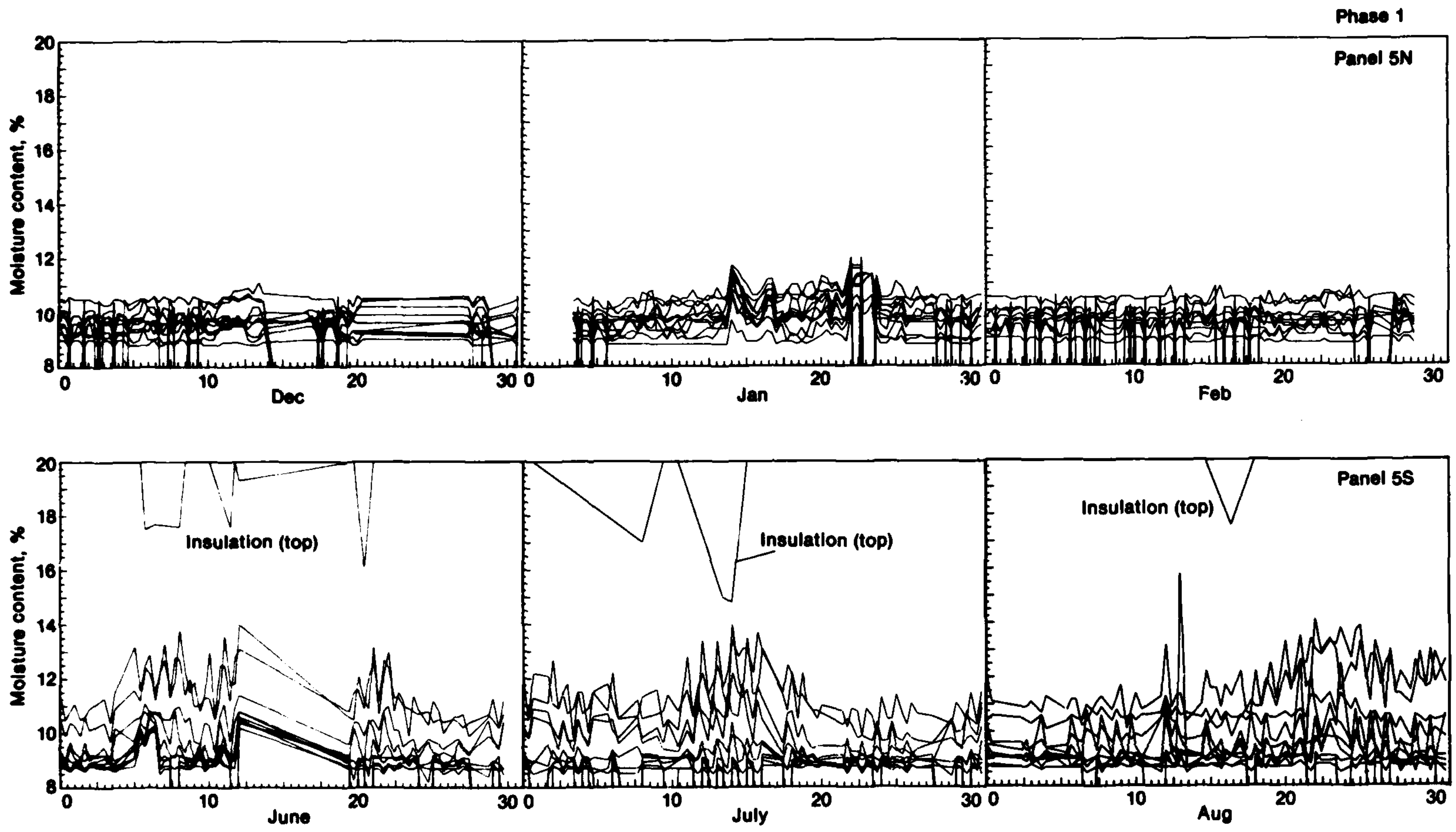

Figure 11.—Moisture content of wood probes in panel 5N (polyethylene, R-19 glass fiber, fiberboard), December 1979 through February 1980; and in panel 5S, June through August 1980. (ML85 5045)

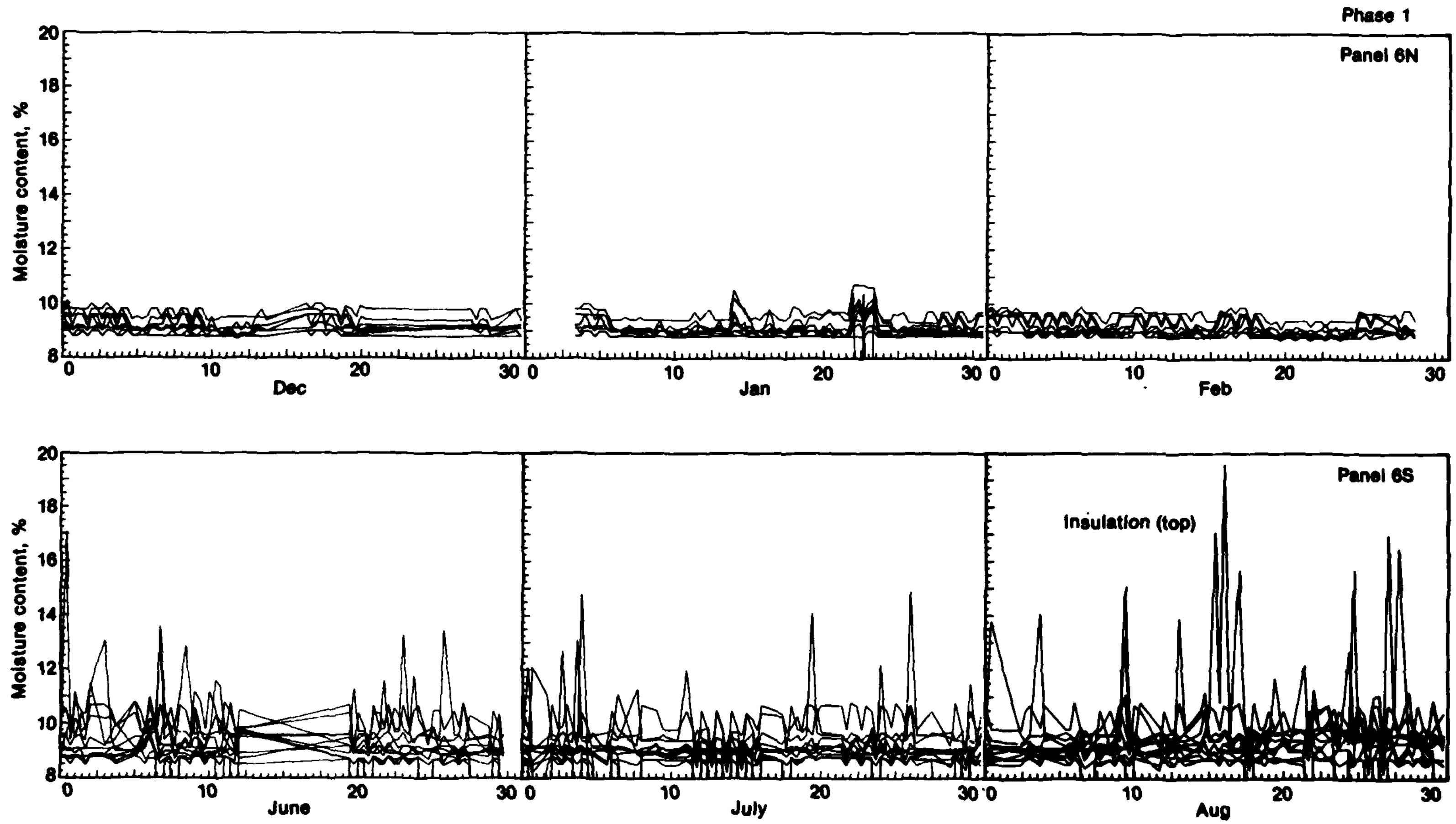

Figure 12.—Moisture content of wood probes in panel 6N (polyethylene, R-13 glass fiber, polystyrene), December 1979 through February 1980; and in panel 6S, June through August 1980. (ML85 5046)

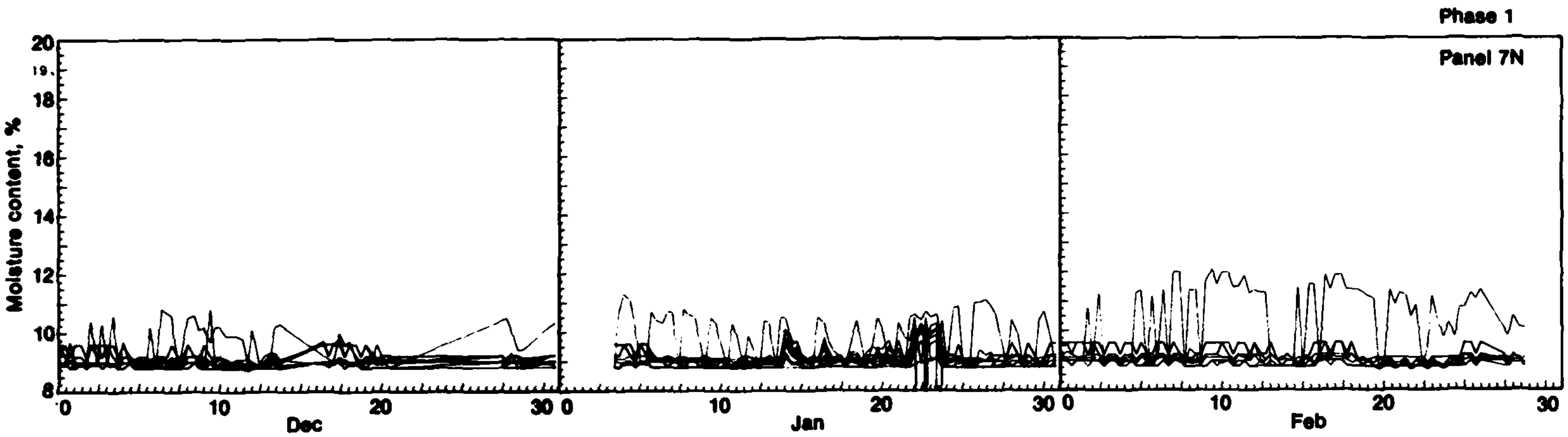

Figure 13.—Moisture content of wood probes in panel 7N (asphalted paper, R-11 glass fiber, polystyrene), December 1979 through February 1980. Data from panel 7S are not shown because construction damage allowed intrusion of outdoor air into the panel, thereby invalidating the data. (ML85 5047)

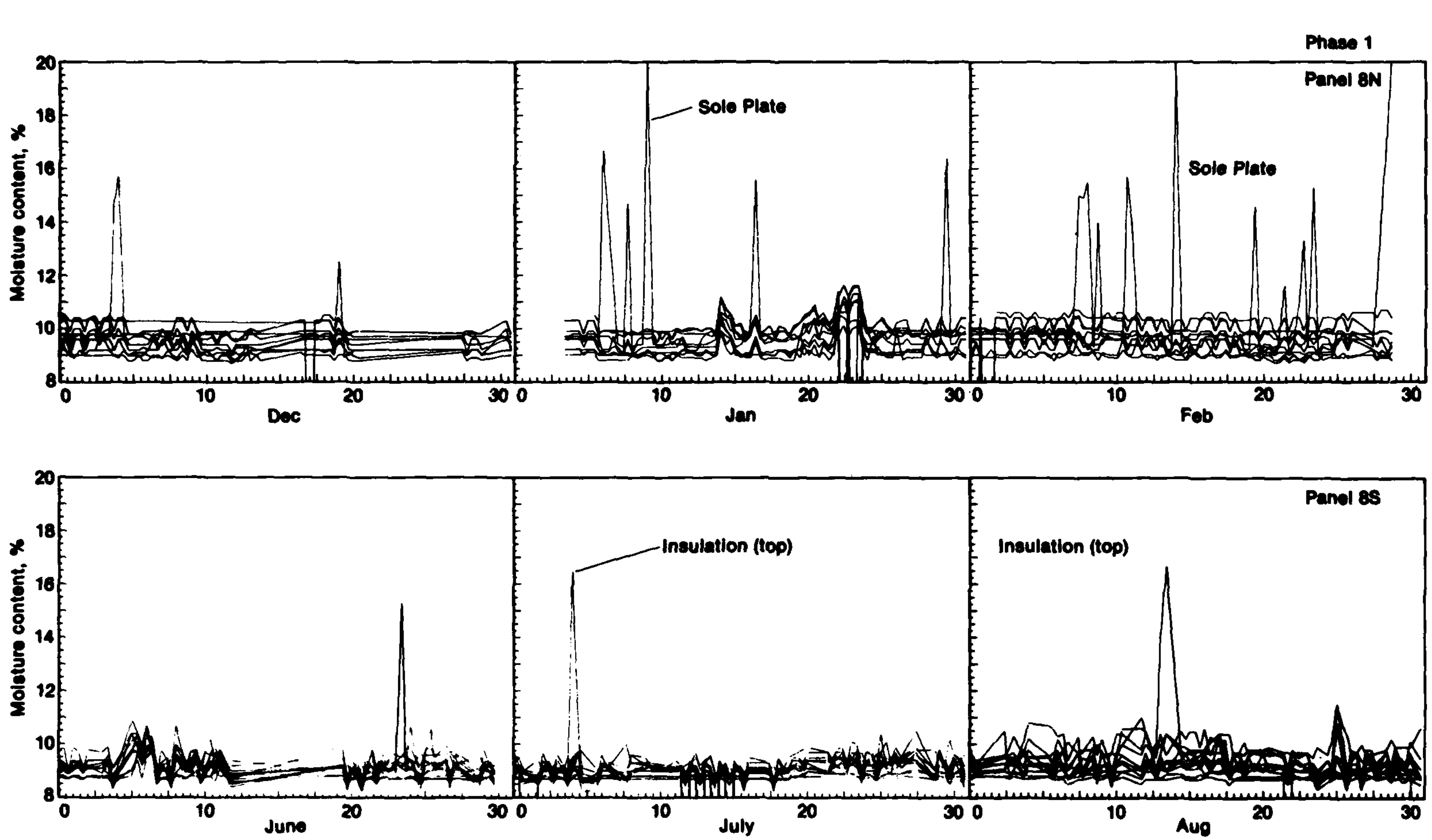

Figure 14.—Moisture content of wood probes in panel 8N (polyethylene, R-13 glass fiber, vented foil-backed isocyanurate), December 1979 through February 1980; and in panel 8S, June through August 1980. (ML85 5049)

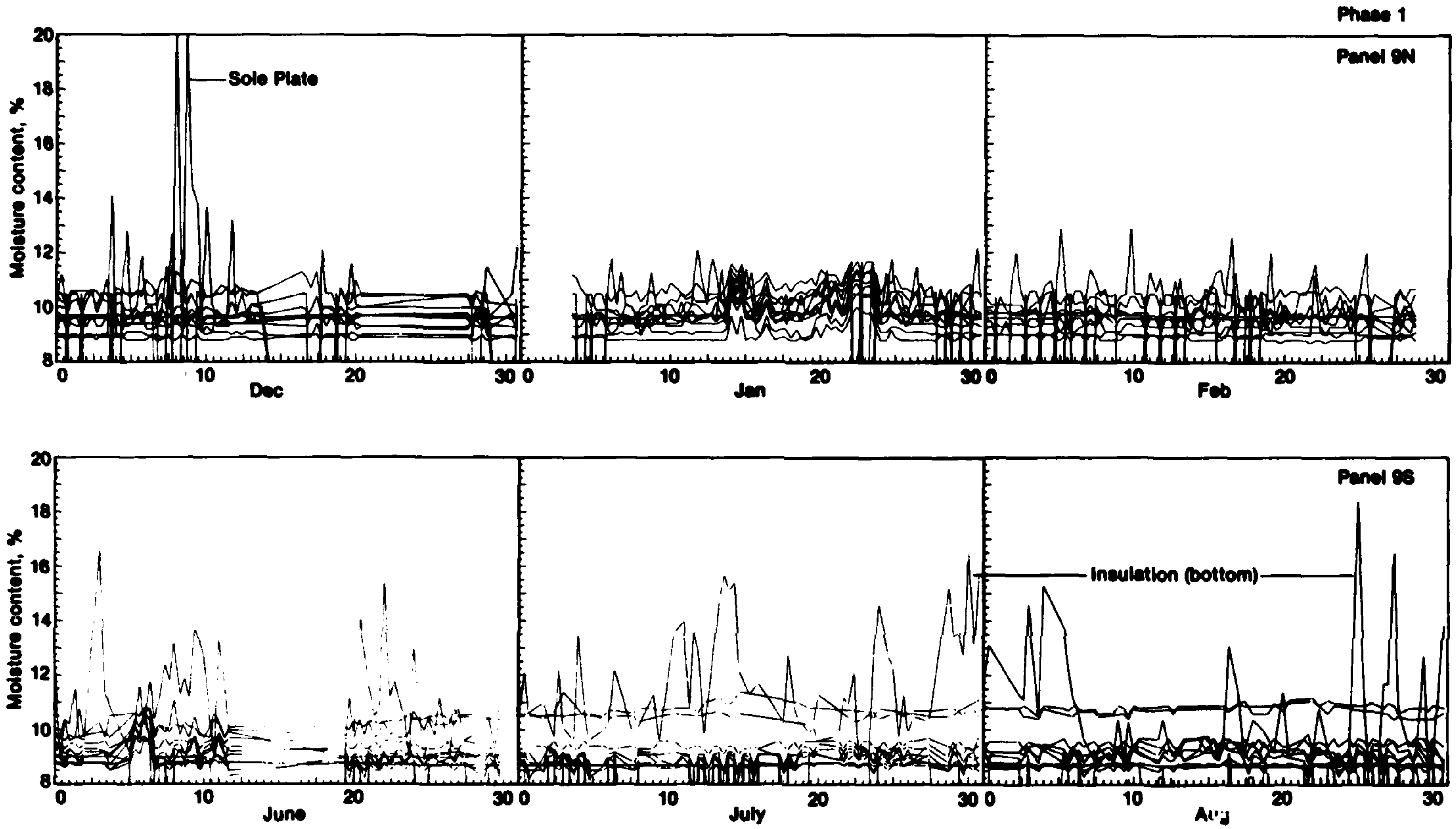

Figure 15.—Moisture content of wood probes in panel 9N (polyethylene, R-13 glass fiber, foil-backed isocyanurate), December 1979 through February 1980; and in panel 9S, June through August 1980. (ML85 5048)

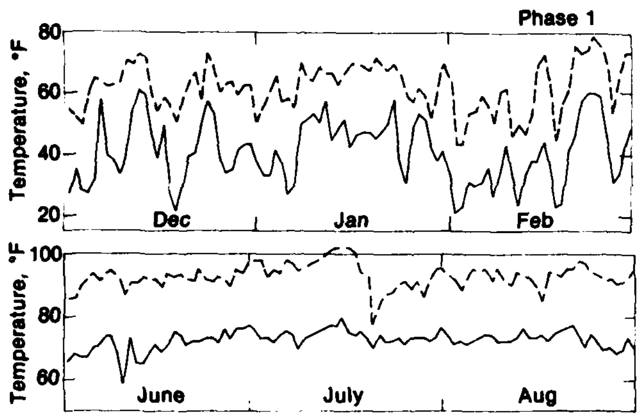

Figure 16.—High and low outdoor temperatures during Phase 1, December 1979 through February 1980 and June through August 1980. (ML85 5059)

Phase 2—Outlet Penetrations

Moisture in all north panels during December 1980 and January and February 1981 (Phase 2) is plotted in figures 17 through 24. High and low outdoor temperatures for Phase 2 plots are shown in figure 25. Moisture in all southfacing panels during June and July 1981 is also plotted in figures 17 through 24. Heating and cooling degree-days for these time periods are shown in table 1. A direct lightning strike near the end of July resulted in discontinuing the data collection. Complete replacement of the instrumentation would have been required for continued operation.

Moisture levels in all the panels increased after the walls were penetrated by electrical outlets (table 3). Instead of being in the low range as during the previous winter, readings were in the moderate range through both the winter and summer. Panels 2N through 6N had no readings above the moderate level during the winter months. Panel 7N had short periods of high moisture in the sole plate. Since no other moisture probes in that panel had elevated moisture levels and condensation would be expected to occur in other parts of the wall before it would occur on the sole plate, it is expected that the sole plate was being influenced by an outside moisture source such as rain or outdoor humidity.

The other panels that had elevated moisture levels were panels 8N and 9N. Rooms 8 and 9 both had RH's of 60 to 70 percent during the winter compared to about 40 percent in all other rooms. There was no moisture being added to any of the rooms, so the only moisture source was residual moisture from the previous summer. Most of the rooms dried out as they were heated, but Rooms 8 and 9 retained moisture. This may have been caused by the sheathing, which was essentially impermeable to water vapor. This possibility is supported by the study of the cold winter climate (Sherwood 1983) in which considerably less water was required to humidify Rooms 8 and 9 than to humidify the other rooms. The high humidity condition would not necessarily exist in an occupied building with ventilation from exhaust vents, opening doors, and leakage around windows.

During the summer of 1981, most of the MC's in all panels remained in the moderate range. Panel 2S had some MC's in the high range that appeared to be from outside influences. The highest level was at the siding-sheathing interface. The MC of the stud near the bottom moved also slightly into the high range at times, but there was no increase of MC at other locations in the wall. Panels 3S and 4S had no MC's in the high level at any time. Panels 6S and 9S both had several one-time readings of 20 percent, but there was no extended period of condensation in either panel.

The only panel with any extended period of condensation was, again, panel 5S. MC readings indicated that insulation near the bottom became wet in late June and remained wet through the recording period in late July. The stud near the bottom also showed MC's of 20 percent for a period of 5 days in July. Other moisture probes near the bottom of the wall cavity had readings in the high range. At the end of the summer, panel 5S was opened for inspection and the insulation was found to be wet. The MC of the framing was determined by a moisture meter and found to be about 16 percent.

The overall results from the walls with penetrations are summarized as follows:

1. The MC at all points in all the panels increased about 1 to 3 percent after the walls were penetrated by an electrical outlet.
2. None of the walls had extended periods of condensation during the winter.
3. Under test conditions with all rooms essentially sealed, RH in the rooms with foil-backed sheathing remained higher during winter than in other rooms.
4. Because of the high room RH during winter, panels with foil-backed polyisocyanurate sheathing had high levels of moisture in the walls.
5. The only panel having extended periods of condensation during the summer was the wall with 6-inch studs.

Examination of the Test Structure

After completion of both phases of the test, the experimental wall panels were disassembled and examined for evidence of moisture and verification of test data. Panels were disassembled in place from the outside, beginning with siding and examining each interface of materials as the process continued. One observation was a lack of compression of the foam sheathings at the sole plate, which could have resulted in air leakage at that joint. The examination generally verified test data and provided evidence to support some conclusions. There was no fungal growth or other deterioration in the wood or wood-based materials in any of the test panels. There were adhesions of glass fiber to polyethylene in the fiberboard-sheathed walls and no such adhesions in plywood- or foam-sheathed walls. Since these adhesions are normally due to the presence of water, the low-permeability sheathings appeared to be effective in limiting moisture movement into the wall cavity during the air-conditioning season. Streaking on the polyethylene in fiberboard-sheathed walls and waterstains on sole plates were further evidence that some condensation had occurred for limited time periods and ran down to the sole plate. Even where plates were waterstained, there was no elevation of MC and no fungal growth, indicating that water was present for only brief periods.

Table 3.—Humidity as indicated by moisture content[1] of wood probes in insulation and framing during Phase 2 (with penetrations). Elevated MC's are considered only where at least three consecutive readings are in that range

Panel No.	Insulation-sheathing interface			Sheathing-siding interface			Panel No.	Insulation		Framing	
	December	January	February	December	January	February		June	July	June	July
2N	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	2S	Moderate	Moderate	Moderate	High
3N	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	3S	Moderate	Moderate	Moderate	Moderate
4N	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	4S	Moderate	Moderate	Moderate	Moderate
5N	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	5S	Moderate	Condensation[3]	Moderate	Condensation[3]
6N	Moderate[3]	Moderate[3]	Moderate[3]	Moderate	Moderate	Moderate	6S	Moderate[3]	Moderate[3]	Moderate	Moderate
7N	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	[2]7S	—	—	—	—
8N	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	8S	Moderate	Moderate	Moderate	Moderate
9N	High[3]	High[3]	High[3]	Moderate	Moderate	Moderate	9S	High[3]	Moderate[3]	Moderate	Moderate

[1]Low = <12 percent MC; moderate = 12 to 16 percent; high = 16 to 20 percent; condensation = >20 percent.
[2]Data from panel 7S are not shown because construction damage allowed intrusion of outdoor air into the panel, thereby invalidating the data.
[3]Range of humidity was not replicated on opposite-facing walls for the same time period. The reasons for differences were not resolved, and indicate the need for further study.

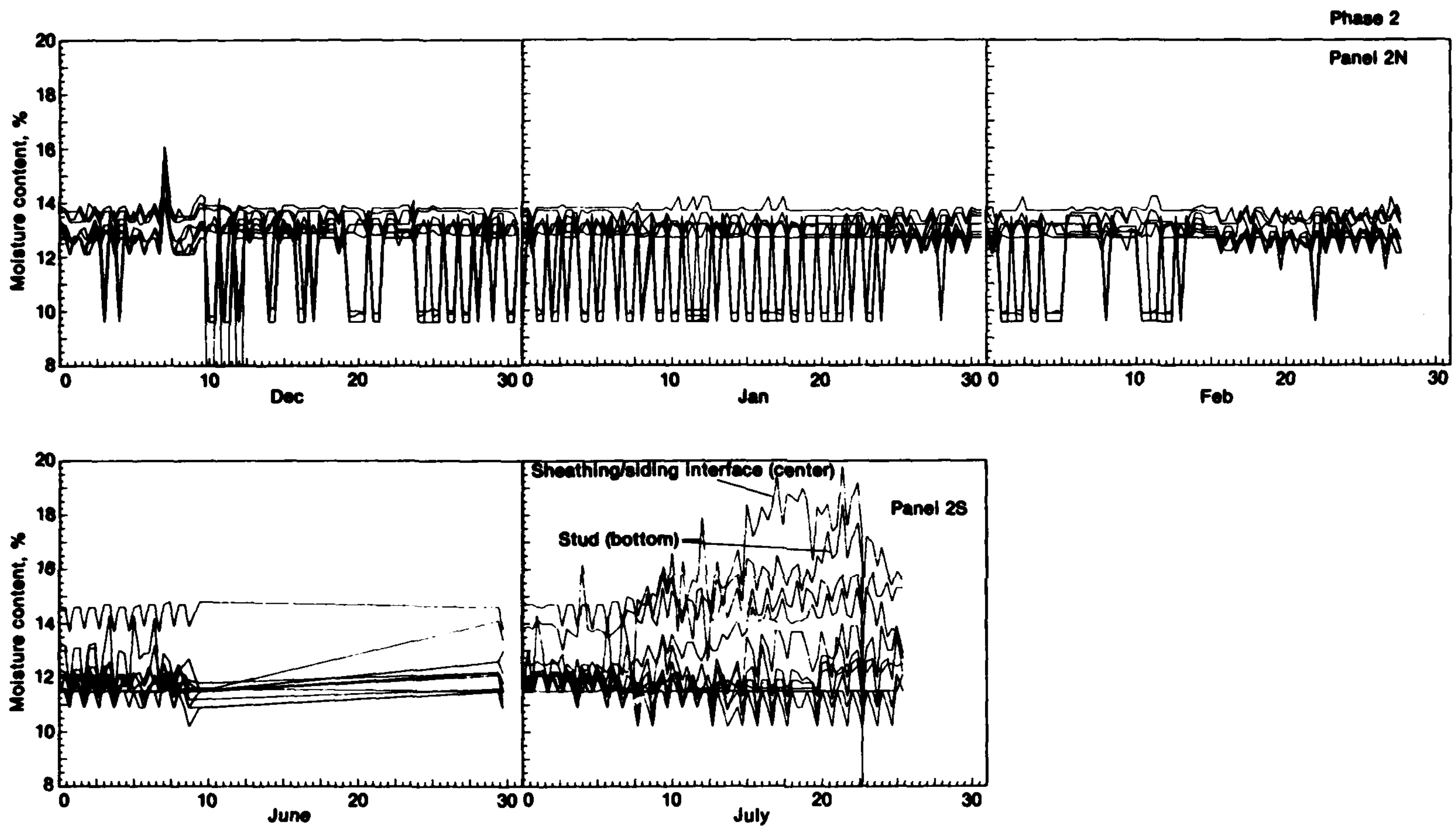

Figure 17.—Moisture content of wood probes in panel 2N (polyethylene, R-13 glass fiber, fiberboard), December 1980 through February 1981; and in panel 2S, June and July 1981. (ML85 5050)

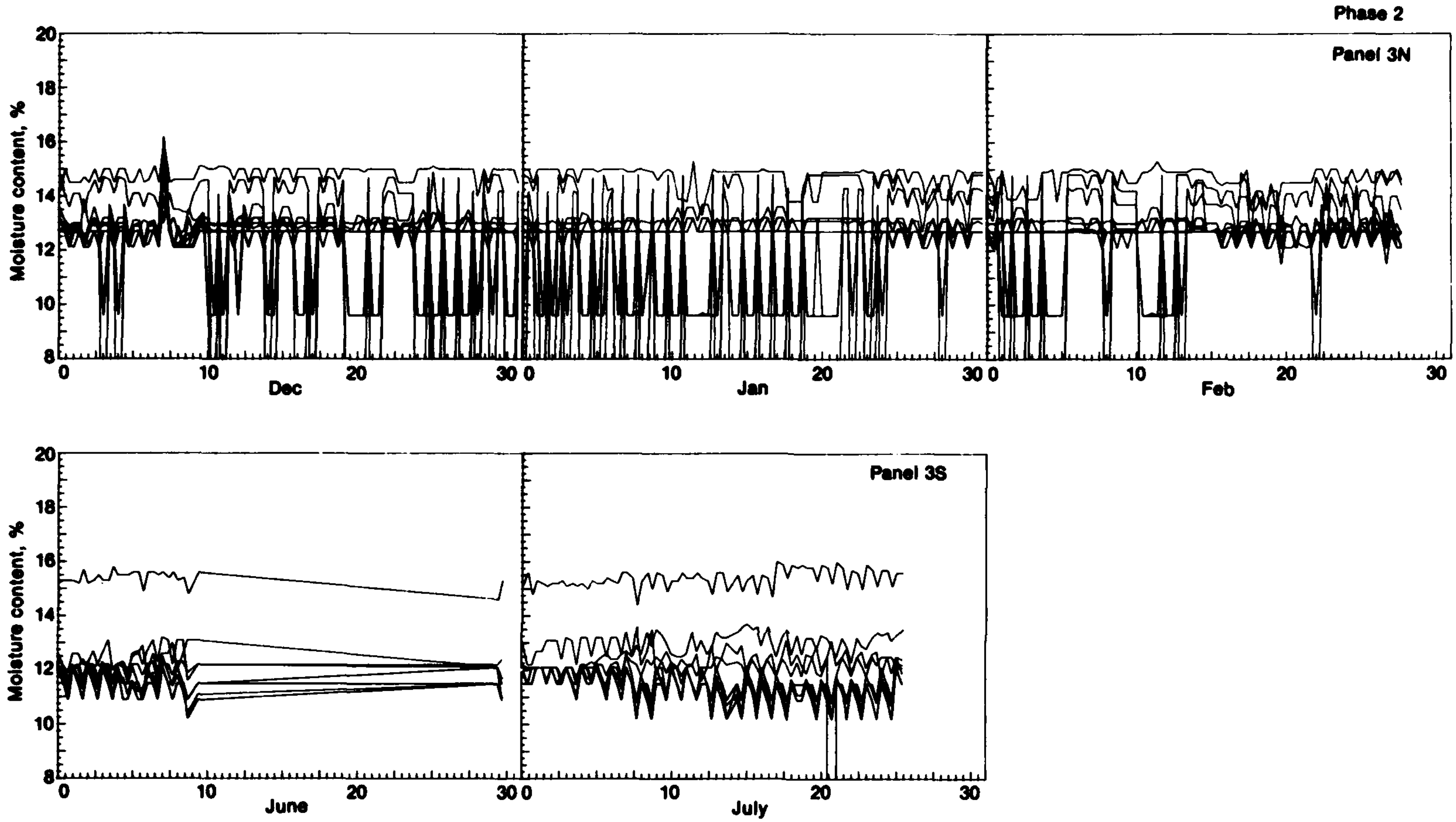

Figure 18.—Moisture content of wood probes in panel 3N (asphalted paper, R-11 glass fiber, fiberboard), December 1980 through February 1981; and in panel 3S, June and July 1981. (ML85 5051)

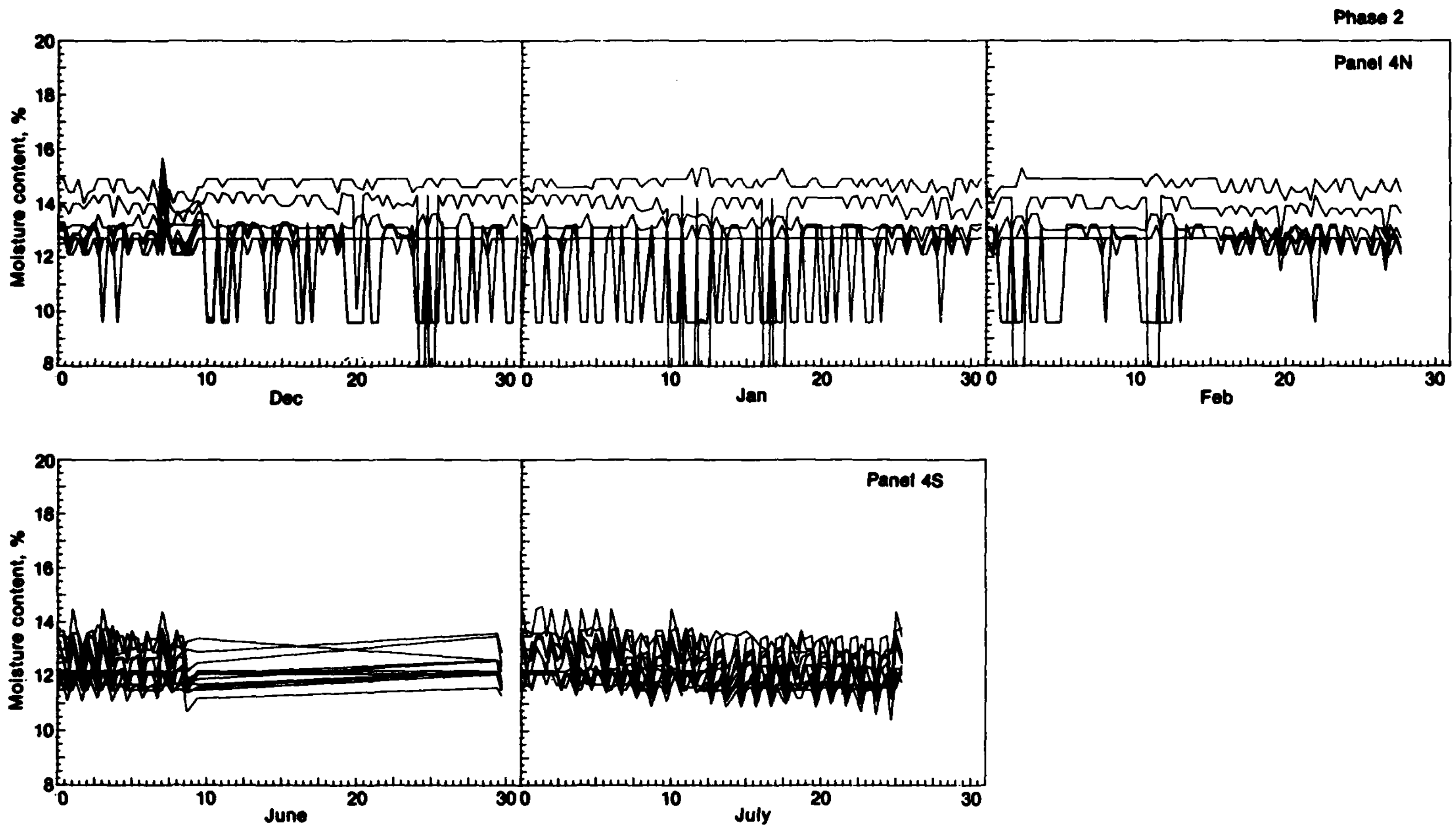

Figure 19.—Moisture content of wood probes in panel 4N (asphalted paper, R-11 glass fiber, plywood), December 1980 through February 1981; and in panel 4S, June and July 1981. (ML85 5052)

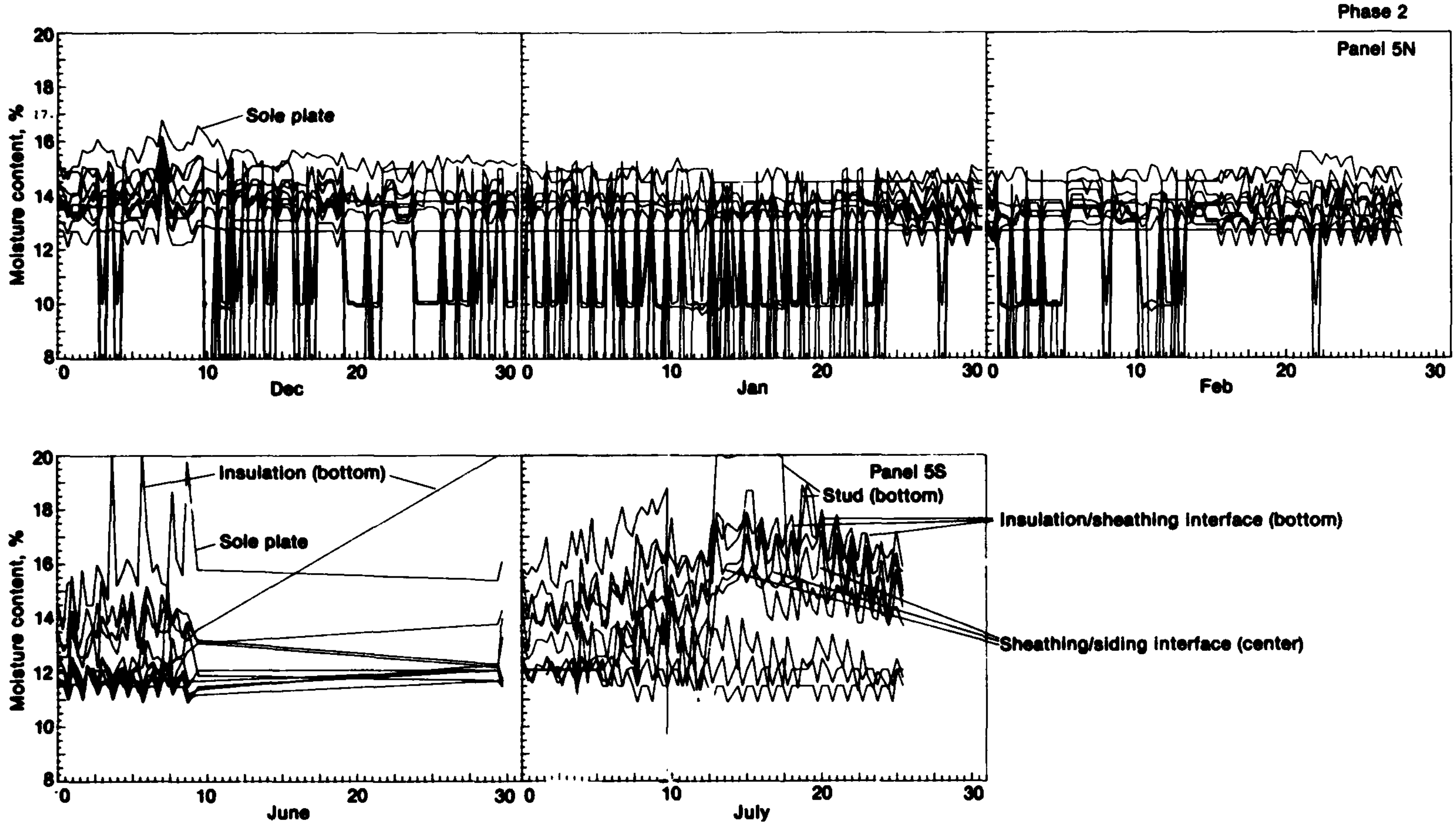

Figure 20.—Moisture content of wood probes in panel 5N (polyethylene, R-19 glass fiber, fiberboard), December 1980 through February 1981; and in panel 5S, June and July 1981. (ML85 5053)

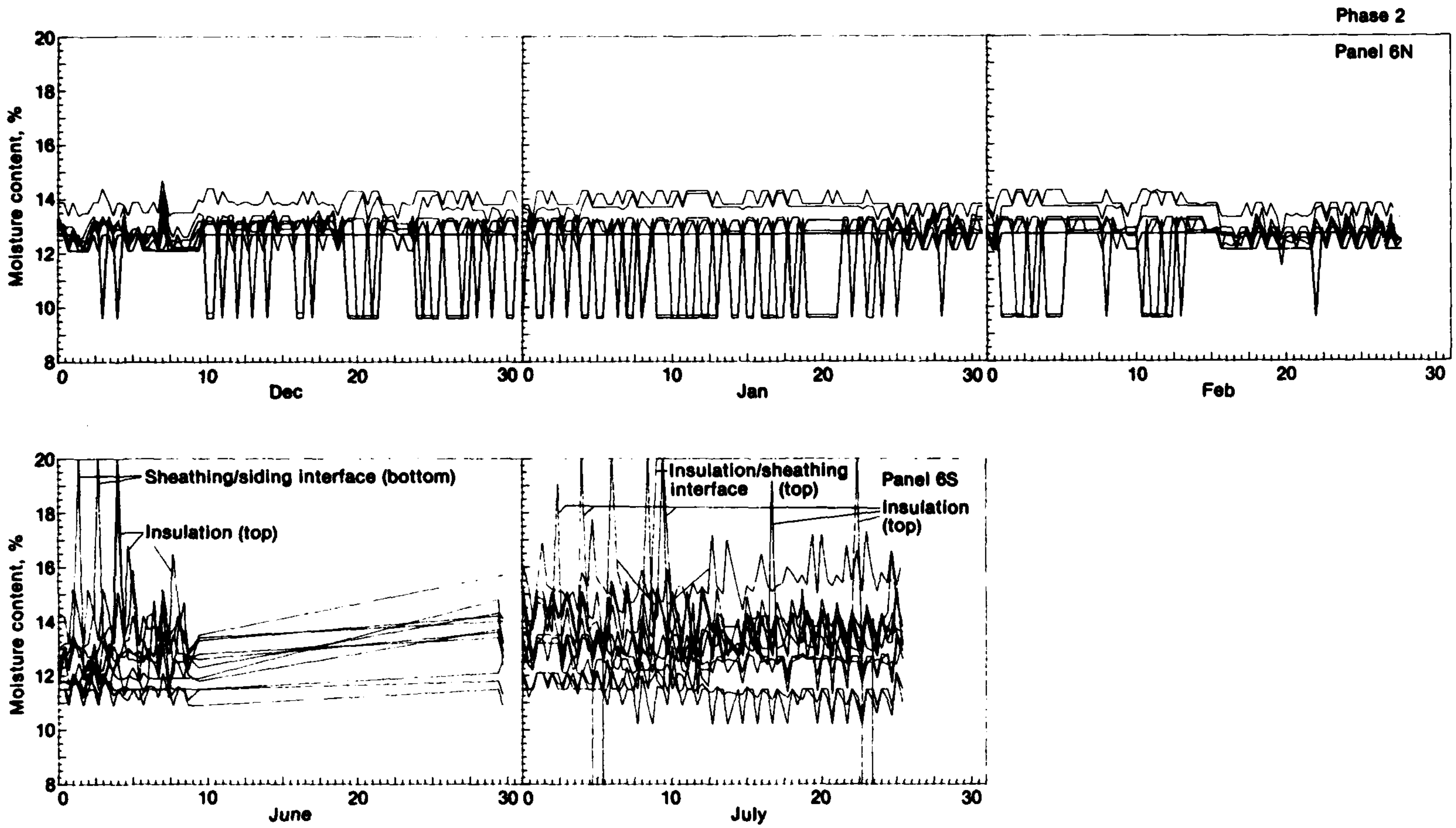

Figure 21.—Moisture content of wood probes in panel 6N (polyethylene, R-13 glass fiber, polystyrene), December 1980 through February 1981; and in panel 6S, June and July 1981. (ML85 5054)

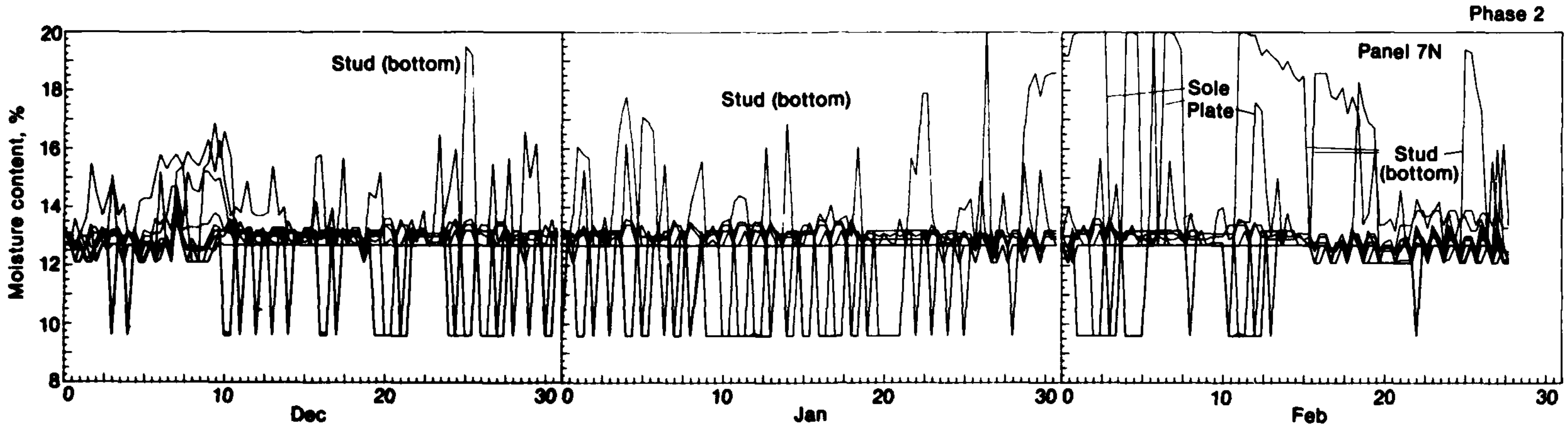

Figure 22.—Moisture content of wood probes in panel 7N (asphalted paper, R-11 glass fiber, polystyrene), December 1980 through February 1981. Data from panel 7S are not shown because construction damage allowed intrusion of outdoor air into the panel, thereby invalidating the data. (ML85 5055)

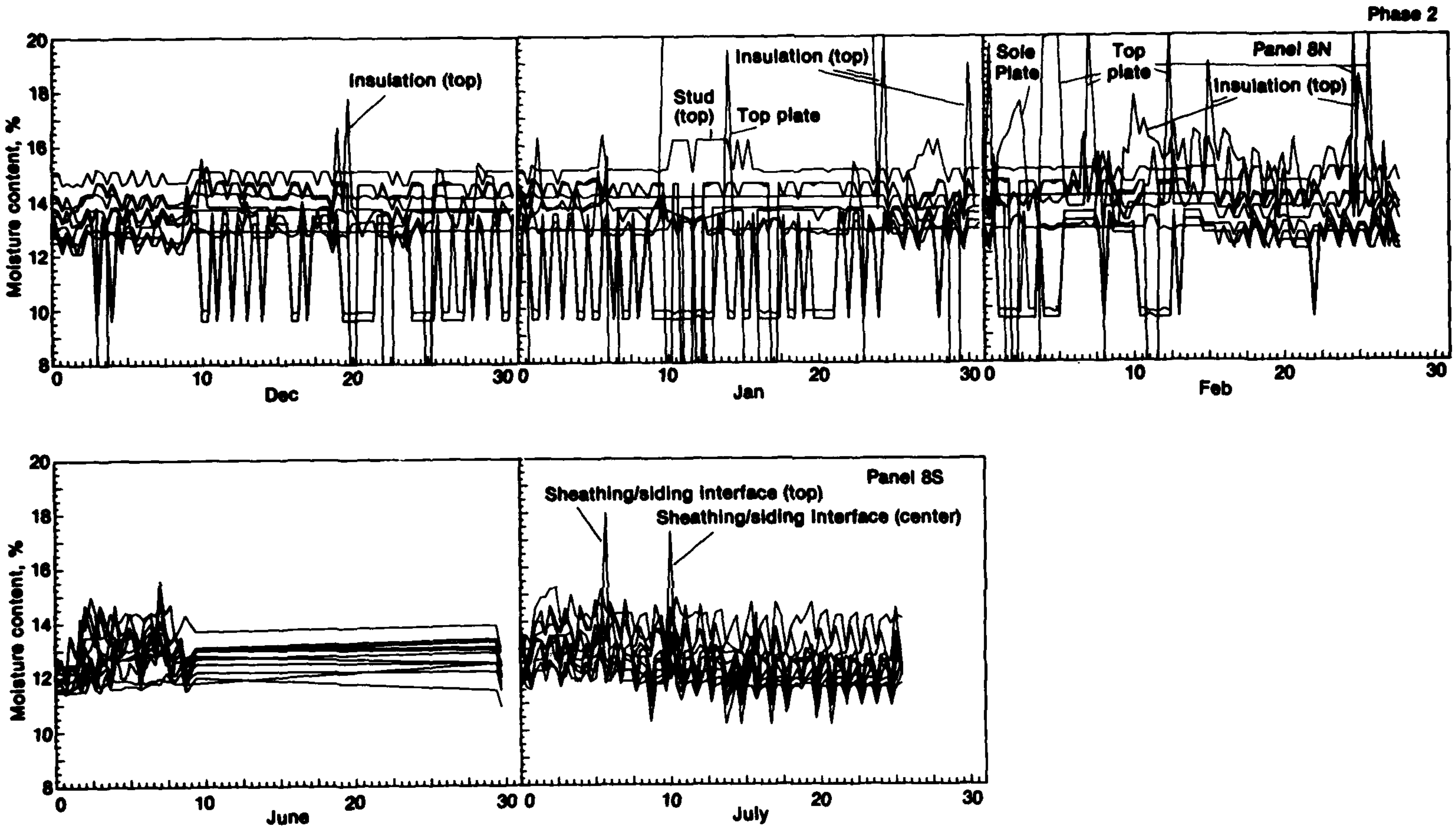

Figure 23.—Moisture content of wood probes in panel 8N (polyethylene, R-13 glass fiber, vented foil-backed isocyanurate), December 1980 through February 1981; and in panel 8S, June and July 1981. (ML85 5057)

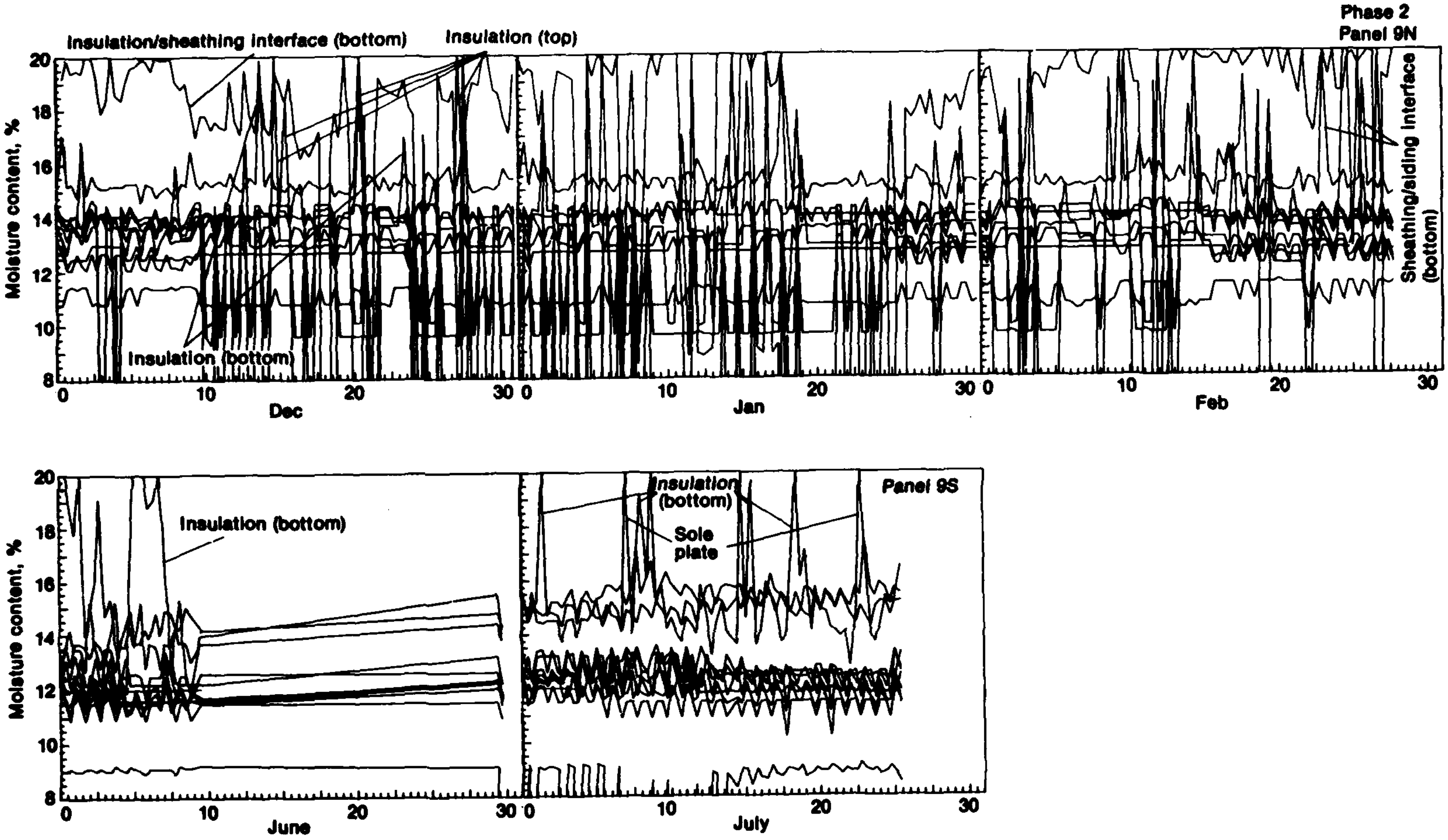

Figure 24.—Moisture content of wood probes in panel 9N (polyethylene, R-13 glass fiber, foil-backed isocyanurate), December 1980 through February 1981; and in panel 9S, June and July 1981. (ML85 5056)

Findings

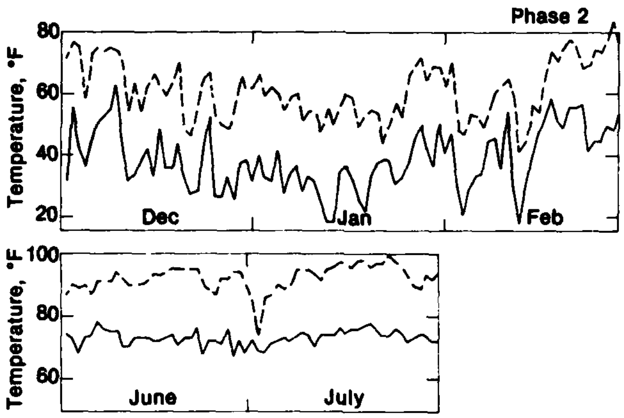

Figure 25.—High and low outdoor temperatures during Phase 2, December 1980 through February 1981 and June through July 1981. (ML85 5058)

The following findings apply to the climate of Gulfport, MS, at controlled indoor conditions of 67 to 70 °F during winter and 76 to 79 °F during summer. Indoor RH did not go below 40 percent during winter and was not controlled during summer. The test building was electrically heated so there were no pressure changes due to combustion air requirements. Air-conditioner fans operated only when the air conditioner was running; ceiling fans operated when either the heater or air conditioner was running.

1. No condensation was detected in any of the walls during the first winter with no penetrations in the walls (Phase 1).
2. The only wall with sustained condensation during the first summer with no penetrations in the walls (Phase 1) was the wall with 6-inch studs.
3. The MC at all points in all walls increased from about 11 percent to about 14 percent when the walls were penetrated by an electrical outlet (Phase 2).
4. Although some walls had periods of elevated MC's during the second winter with penetrations (Phase 2), there were no extended periods of condensation recorded.
5. Rooms with foil-backed foam sheathing had winter RH's of about 70 percent compared to 40 percent in other rooms. This occurred both with and without penetrations.
6. The only room having extended periods of condensation during the second summer with penetrations (Phase 2) was the wall with 6-inch studs.
7. Framing in the wall with 6-inch studs had MC's of about 16 percent at the end of the summer in both Phase 1 and Phase 2.
8. Penetration of vapor retarders increased MC's in walls both in winter and summer.
9. Moisture was driven from hygroscopic sheathing in south walls resulting in greater moisture increase than in north walls. This difference did not exist between north and south walls where nonhygroscopic foam sheathing was used.
10. Low-permeance sheathings reduced the movement of outdoor moisture into the wall cavity of air-conditioned buildings.
11. There was no deterioration of any wood or wood products in any type of wall construction tested.

Conclusions

The findings of this study are limited to specific indoor and outdoor conditions; they should, however, be relevant to the southeastern United States. Where summer temperatures are consistently higher, the summer condensation potential is greater. Where winter temperatures are consistently lower, the winter condensation is greater; however, the indoor humidity may be lower in colder climates, which would reduce the condensation potential.

All of the walls performed satisfactorily during the winters both with and without penetrations. Winter condensation was not a hazard in any of the wall constructions tested.

Penetrating walls with electrical outlets results in elevating MC's in all walls from about 11 percent to about 14 percent. Where summer condensation occurs over an extended time, MC of framing members may rise as high as 16 percent. Even where extended periods of condensation occur, walls dry out in the fall as temperatures drop. The complete absence of fungal growth in any of the wall panels indicates that the potential for deterioration of wood or wood products is minor.

Because the walls with plywood or foam sheathing had no evidence of high moisture levels during the summer, and fiberboard-sheathed panels had evidence of condensation on the vapor retarder, some resistance to diffusion of water vapor from the outside face of the wall appears to be an advantage. A nonhygroscopic sheathing also appears to be an advantage where summer sun shines on the wall. If sheathing is hygroscopic, moisture is driven from the sheathing into the wall cavity, allowing the dry sheathing to take on more moisture from outdoor air when the sun is not shining. The cycle can then be repeated, resulting in a very humid condition in the wall cavity. The type of vapor retarder had no observable effect on moisture in walls during summer.

These conclusions apply only to conventional construction and the indoor conditions stated. Higher humidities may occur due to construction moisture, extremely tight construction, or major indoor sources such as numerous house plants, unvented clothes driers, etc. Also, some manufactured houses may be constructed in a manner that greatly limits air movement through the wall cavity, and thus moisture patterns may be different.

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